Editorial

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With worldwide increase in energy demand, the interest in deep subsurface energy extraction, energy storage and disposal of energy waste has also increased in the recent years. Deep subsurface energy extraction technologies include both conventional sources of energy such as hydrocarbons (e.g. coal, oil and gas), and unconventional sources of energy, including coalbed methane, shale gas, underground coal gasification, methane hydrate and deep geothermal. Considering the extreme environment in deep subsurface conditions and limited knowledge of the geological and petrophysical properties of the target formation, a considerable degree of uncertainties in the long-term performance of the deep subsurface applications currently exist. The uncertainties may lead to undesired and unpredicted hazards such as leakage of chemicals, gas and waste into shallower formations. This themed issue offers a selection of seven scientific papers that describe advances and challenges involved in deep subsurface energy applications as well as associated environmental impacts. The issue covers a range of studies and applications in the field of carbon sequestration, energy storage, hydrocarbon/geothermal reservoirs, and high-level radioactive waste disposal.

In relation to carbon sequestration, Mortezaei *et al.* (2021) have provided a review on recent advances in modelling of CO₂ leakage from storage sites, as well as presenting an overview of potential environmental impacts as the results of CO₂ leakage to upper formations and the atmosphere. A number of techniques for monitoring and detection of gas leakage including remote sensing and time-laps seismic survey are reviewed and discussed. The challenges in prediction and quantification of carbon dioxide (CO₂) leakage are also discussed which are mainly attributed to the temporal and spatial uncertainties associated with the properties of the storage reservoir.

Cholewinski and Leonenko (2021) on the other hand, have studied a different aspect of CO₂ sequestration by evaluating diffusion-controlled CO₂ dissolution within the pipeline before injecting into the ground. Both turbulent and laminar dissolution regimes are considered in a series of numerical modelling to understand the feasibility of ex-situ CO₂ dissolution before injection for improved risk management.

Chen and Lai (2021) have presented a numerical study of hydromechanical modelling of CO₂ sequestration using a component-based multiphysics code ‘Albany’ which is an emerging powerful and open-source platform for finite element method-based solutions employed for automatic differentiation technique, to derive Jacobian matrices or analytical consistent tangent moduli automatically. Numerical tools that consider the complete physics

of a geological CO₂ sequestration system under realistic field conditions do not yet exist, however, the work presented in this paper is a first step towards that.

In the area of energy storage, Amirlatifi *et al.* (2021) present a study on reusing abandoned natural gas storage (NGS) sites for compressed air energy storage (CAES). The study explores the advantages of converting NGS sites into CAES in comparison with conventional energy storage methods and evaluates their feasibility based on a number of site-specific economic analyses.

Babaei and Sedighi (2021) have carried out 3D numerical simulations to capture acidizing process to enhance the injectivity and productivity of the hydrocarbon or heat recovery from hydrocarbon or geothermal reservoirs. They investigated the influence of lithological heterogeneity of the rock on reactive transport of acid in the porous media. The study highlighted the mechanical stability of developed wormholes and their dependence on the correlation lengths of the porous system are very important in the design of the acidizing operation.

First time a study on the impact of pile foundations on gas flow from the ground was investigated in Wilson and Mortimer (2021). They documented a number of case studies investigating different types of pile construction techniques causing gas migration through preferential pathways formed during the construction. They concluded gas pressure, horizontal ground permeability and pile spacing are the critical factors controlling gas migration.

High-level radioactive waste is subjected to strongly coupled thermal, hydrodynamic, geochemical and mechanical (THCM) processes. Samper *et al.* (2021) presented THCM numerical simulations of lab to field scale studies intended for radioactive waste disposal. They found mineral dissolution/precipitation of corrosion products in the long run can significantly reduce the porosity of the bentonite near the canister and causes pore clogging.

The subsurface has a crucial role in the decarbonisation of our energy system, hence subsurface energy resources are also part of the decarbonisation picture. Geological storage of carbon dioxide, deep geothermal, compressed air storage and radioactive waste disposal may all have a role to play whilst the world transitions from fossil fuels to more renewable sources of energy. Emerging technologies and development of new monitoring techniques, strategies and advanced computer models can help us to enhance our understanding of deep subsurface and crucially improve our predictions of potential hazards associated with deep energy applications.

Finally, we would like to thank all our contributors for their great efforts in preparing the manuscripts and for their cooperation and patience throughout the review process.

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